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INTERNATIONAL APPLICATION

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DESCRIPTION

PIEZOELECTRIC ELECTROACOUSTIC TRANSDUCER

Technical Field

The present invention relates to piezoelectric electroacoustic transducers such as piezoelectric sounders, piezoelectric receivers, and piezoelectric speakers.

Background Art

Piezoelectric electroacoustic transducers for emitting warning sounds or operating sounds have been widely used in electronic devices, consumer products, and cellular phones, for example, as piezoelectric sounders or piezoelectric receivers. Piezoelectric electroacoustic transducers incorporating a rectangular diaphragm have been proposed to achieve higher production efficiency, higher electroacoustic conversion efficiency, and size reduction.

Extremely thin diaphragms, on the order of tens to hundreds of micrometers in thickness, have recently been used for lower frequencies. The frequency characteristics of such thin diaphragms are greatly affected by structures supporting the diaphragms.

If, for example, a diaphragm is directly connected to terminals fixed to a casing using a thermosetting conductive adhesive, a stress

due to the curing and contraction of the conductive adhesive causes a strain on the diaphragm. This strain results in variations in the frequency characteristics of the diaphragm. In addition, the cured conductive adhesive can disadvantageously obstruct the vibration of the diaphragm or, conversely, can be cracked by the vibration thereof because the cured adhesive has a relatively high Young's modulus.

Patent Document 1 proposes a piezoelectric electroacoustic transducer including a piezoelectric diaphragm, a casing having a support on an inner portion thereof to support the bottom surface of the piezoelectric diaphragm at two or four sides thereof, terminals having inner connection portions exposed near the support, a first elastic adhesive applied between the periphery of the piezoelectric diaphragm and the inner connection portions of the terminals to fix the piezoelectric diaphragm to the casing, a conductive adhesive applied between electrodes of the piezoelectric diaphragm and the inner connection portions of the terminals across the top surface of the first elastic adhesive to electrically connect the electrodes of the piezoelectric diaphragm to the inner connection portions of the terminals, and a second elastic adhesive provided to seal a gap between the periphery of the piezoelectric diaphragm and the inner portion of the casing. The first elastic adhesive used is, for

example, a urethane adhesive. The second elastic adhesive used is a material with a lower Young's modulus than the first elastic adhesive, for example, a silicone adhesive.

In this case, the elasticity of the first elastic adhesive prevents, for example, variations in the frequency characteristics of the diaphragm which are caused by a stress due to the curing and contraction of the conductive adhesive and the cracking of the cured conductive adhesive. The support, however, can restrain the piezoelectric diaphragm and obstruct the bending vibration thereof because the support supports the piezoelectric diaphragm at two or four sides thereof.

Patent Document 2 discloses a piezoelectric electroacoustic transducer including a piezoelectric diaphragm, a casing having supports for supporting the bottom surface of the piezoelectric diaphragm at the four corners thereof, a first elastic adhesive applied between the piezoelectric diaphragm and terminals near the supports, and a conductive adhesive applied across the first elastic adhesive to electrically connect the piezoelectric diaphragm to the terminals.

In this case, the supports have a small supporting area because they support only the corners of the piezoelectric diaphragm. This electroacoustic transducer can produce a higher sound pressure

without restraining the diaphragm.

A piezoelectric electroacoustic transducer having supports for supporting a piezoelectric diaphragm at the corners thereof can thus produce a higher sound pressure. A smaller diaphragm-supporting area is demanded for further size reduction and still higher sound pressures, and a smaller diaphragm thickness is demanded for lower frequencies. A thinner diaphragm, however, bends more easily, and a drop impact, for example, can cause a large curvature of the diaphragm if the supporting area is small. A large curvature of the diaphragm causes a large amplitude of vibration thereof in the vicinity of the conductive adhesive, and an excessive stress acts on the conductive adhesive accordingly. The excessive stress can disadvantageously contribute to the cracking of the conductive adhesive, thus degrading the connection reliability of products.

Fig. 14 illustrates sectional views of a support supporting a piezoelectric diaphragm in the known art.

In Fig. 14(a), a support 32 supports a corner of a diaphragm 30. An elastic adhesive 34 is applied between the diaphragm 30 and a terminal 33 inserted in a case 33. The elastic adhesive 34 used is, for example, a urethane adhesive. A conductive adhesive 35 is applied across the elastic adhesive 34 to electrically connect an

electrode of the diaphragm 30 to the terminal 33.

In this support structure, the diaphragm 30 bends downward with the support 32 as a fulcrum if a drop impact, for example, applies a downward acceleration G to the diaphragm 30, as shown in Fig. 14(b). The downward bending can then impose a tensile stress on the conductive adhesive 35 and cause a crack 35.

Patent Document 3 discloses a piezoelectric sounder including a unimorph piezoelectric diaphragm and a case having curvature-preventing columns extending from the bottom surface thereof. The curvature-preventing columns limit the curvature of the piezoelectric diaphragm if a drop impact, for example, applies an external force exceeding the bending strength of the diaphragm. The curvature-preventing columns, however, are intended to prevent the cracking of the piezoelectric diaphragm itself and the delamination of a ceramic plate from a metal plate, and no consideration is given to the cracking of a conductive adhesive as described above.

Patent Document 1: Japanese Unexamined Patent Application Publication No. 2003-9286

Patent Document 2: Japanese Unexamined Patent Application Publication No. 2003-23696

Patent Document 3: Japanese Unexamined Utility Model Registration

Application Publication No. 7-16500

Disclosure of Invention

Problems to be Solved by the Invention

An object of the present invention is to provide a piezoelectric electroacoustic transducer that can avoid an excessive curvature of a piezoelectric diaphragm due to, for example, a drop impact to prevent the cracking of a conductive adhesive.

Means for Solving the Problems

To achieve the above object, the invention according to Claim 1 provides a piezoelectric electroacoustic transducer including a rectangular piezoelectric diaphragm that is supplied with a periodic signal across electrodes thereof to bend and vibrate in a thickness direction; a casing having supports on an inner portion thereof to support the four corners of the bottom surface of the piezoelectric diaphragm; terminals fixed to the casing, each having an inner connection portion exposed near the supports; a first elastic adhesive applied between the periphery of the piezoelectric diaphragm and the inner connection portions of the terminals to secure the piezoelectric diaphragm to the casing; a conductive adhesive applied between the electrodes of the piezoelectric diaphragm and the inner

connection portions of the terminals across the top surface of the first elastic adhesive to electrically connect the electrodes of the piezoelectric diaphragm to the inner connection portions of the terminals; a second elastic adhesive filling and sealing a gap between the periphery of the piezoelectric diaphragm and the inner portion of the casing; and an overamplitude-preventing receiver disposed on the casing to limit the amplitude of vibration of the piezoelectric diaphragm to a predetermined range. The overamplitude-preventing receiver is positioned closer to the center of the piezoelectric diaphragm than the supports. The second elastic adhesive fills a gap between the bottom surface of the piezoelectric diaphragm and the top surface of the overamplitude-preventing receiver.

The supports are provided on the inner portion of the casing to support and hold the four corners of the bottom surface of the piezoelectric diaphragm without excessively restraining the diaphragm. The piezoelectric diaphragm can more easily be displaced to produce a higher sound pressure because the supports support only the corners of the piezoelectric diaphragm. A drop impact, however, can bend the piezoelectric diaphragm with a large curvature and thus crack the conductive adhesive, which connects the electrodes of the piezoelectric diaphragm to the inner connection portions of the terminals.

In the present invention, the overamplitude-preventing receiver is provided closer to the center of the piezoelectric diaphragm than the supports to limit the amplitude of vibration of the piezoelectric diaphragm to a predetermined range. In addition, the second elastic adhesive fills the gap between the bottom surface of the piezoelectric diaphragm and the top surface of the overamplitude-preventing receiver to softly support the bottom surface of the piezoelectric diaphragm when the diaphragm is bent. The second elastic adhesive can thus remove an impact on the piezoelectric diaphragm to eliminate problems such as cracking.

According to Claim 2, the distance between the bottom surface of the piezoelectric diaphragm and the top surface of the overamplitude-preventing receiver is preferably 0.01 to 0.2 mm.

If the distance exceeds 0.2 mm, the electroacoustic transducer cannot prevent the overamplitude vibration of the piezoelectric diaphragm, and thus, for example, the conductive adhesive is more easily cracked. If the distance falls below 0.01 mm, the second elastic adhesive has a small thickness between the piezoelectric diaphragm and the overamplitude-preventing receiver. As a result, the overamplitude-preventing receiver tends to obstruct the displacement of the piezoelectric diaphragm and thus decreases sound pressure.

According to Claim 3, preferably, the first elastic adhesive has a Young's modulus of 500×10^6 Pa or less after being cured, and the second elastic adhesive has a Young's modulus of 30×10^6 Pa or less after being cured.

That is, the first and second elastic adhesives have such Young's moduli after being cured that they have no significant effect on the displacement of the diaphragm. The displacement of the diaphragm is at least 90% of the maximum displacement thereof if the first and second elastic adhesives have Young's moduli of 500×10^6 Pa or less and 30×10^6 Pa or less, respectively, after being cured. The first and second elastic adhesives thus have no significant effect on the displacement of the diaphragm.

The Young's modulus of the second elastic adhesive is limited to a narrower acceptable range because the operation of the piezoelectric diaphragm is more susceptible to the Young's modulus of the second elastic adhesive. The second elastic adhesive is applied to the periphery of the piezoelectric diaphragm while the first elastic adhesive is partially applied to the piezoelectric diaphragm, namely, only around the corners thereof.

According to Claim 4, the first elastic adhesive used may be a urethane adhesive, and the second elastic adhesive used may be a silicone adhesive.

Silicone adhesives are widely used as elastic adhesives because of the low Young's modulus after curing and the low cost. These adhesives, however, can produce siloxane gas and deposit a coating thereof on, for example, connection portions when cured by heating. This coating causes serious problems such as bonding failure and connection failure when a conductive adhesive is applied. Silicone adhesives are therefore used only after a conductive adhesive is applied and cured. Urethane adhesives, by contrast, avoid the problems associated with the use of silicone adhesives.

Accordingly, a urethane adhesive is used as the first elastic adhesive to secure the piezoelectric diaphragm to the casing and to form a layer underlying the conductive adhesive for electrically connecting the electrodes of the piezoelectric diaphragm to the inner connection portions of the terminals. On the other hand, a silicone adhesive is used as the second elastic adhesive to seal the periphery of the piezoelectric diaphragm. The piezoelectric electroacoustic transducer can therefore achieve excellent vibration characteristics without causing bonding failure or connection failure.

Advantages

According to the invention of Claim 1, as clarified in the

above description, the supports are provided on the inner portion of the casing to support and hold the four corners of the bottom surface of the piezoelectric diaphragm, thereby producing a higher sound pressure. Even if a drop impact, for example, largely bends the piezoelectric diaphragm, the overamplitude-preventing receiver provided on the casing supports the piezoelectric diaphragm to prevent the cracking of the conductive adhesive.

Furthermore, the second elastic adhesive fills the gap between the bottom surface of the piezoelectric diaphragm and the top surface of the overamplitude-preventing receiver. The second elastic adhesive softly supports the bottom surface of the piezoelectric diaphragm when the diaphragm is bent, so that no impact acts on the piezoelectric diaphragm.

Best Mode for Carrying Out the Invention

An embodiment of the present invention will now be described.

First Embodiment

Fig. 1 illustrates a piezoelectric sounder as an example of a surface-mount piezoelectric electroacoustic transducer according to the present invention.

This piezoelectric sounder mainly includes a piezoelectric diaphragm 1, a case 10, and a cover 20. The case 10 and the cover

20 constitute a casing.

Referring to Figs. 2 and 3, the piezoelectric diaphragm 1 in this embodiment includes a substantially square metal plate 2, an insulating layer 3a formed over a surface of the metal plate 2, and a substantially square piezoelectric element 4 bonded and fixed onto the insulating layer 3a. The piezoelectric element 4 is smaller than the metal plate 2. The metal plate 2 is preferably formed of a material with spring elasticity, such as phosphor bronze and 42Ni alloy. The insulating layer 3a may be formed of a coating of a resin such as polyimide and epoxy or an oxide film formed by oxidation.

The piezoelectric element 4 includes two piezoelectric ceramic layers 4a and 4b, an inner electrode 5 disposed therebetween, an outer electrode 6 disposed substantially over the entire top surface of the piezoelectric element 4, and another outer electrode 7 disposed substantially over the entire bottom surface of the piezoelectric element 4. The two piezoelectric ceramic layers 4a and 4b are formed by co-firing green sheets with the inner electrode 5 disposed therebetween. These piezoelectric ceramic layers 4a and 4b are oppositely polarized in the thickness direction thereof, as indicated by the arrows P in Fig. 3. A side of the inner electrode 5 is exposed on an end surface of the piezoelectric element 4 while the opposite side of the inner electrode 5 is separated from the opposite end

surface of the piezoelectric element 4 by a predetermined distance. The outer electrodes 6 and 7 of the piezoelectric element 4 are connected through a side electrode 8 while the inner electrode 5 is connected to a top lead electrode 9b and a bottom lead electrode 9c through another side electrode 9a. The lead electrodes 9b and 9c are small electrodes formed along one side of the piezoelectric element 4 and electrically isolated from the outer electrodes 6 and 7. The side electrode 8 has a length equivalent to one side of the piezoelectric element 4 while the other side electrode 9a has the length corresponding to those of the lead electrodes 9b and 9c. The lead electrodes 9b and 9c are formed on the top and bottom surfaces, respectively, of the piezoelectric element 4 to eliminate the directionality of the piezoelectric element 4 in this embodiment, although the bottom lead electrode 9c may be omitted. In addition, the lead electrodes 9b and 9c may have a length equivalent to one side of the piezoelectric element 4. The bottom surface of the piezoelectric element 4 is bonded to the center of the top surface of the insulating layer 3a using an adhesive 3b (see Fig. 2) such as an epoxy adhesive. The metal plate 2 is larger than the piezoelectric element 4, having an extended portion 2a extended to the outside of the piezoelectric element 4 and continuously covered with the insulating layer 3a.

Referring to Figs. 4 to 10, the case 10 is formed of a resin and has a rectangular box shape with a bottom wall 10a and four sidewalls 10b to 10e. The case 10 has a size of 9 mm by 9 mm by 2 mm. The resin used is preferably a heat-resistant resin such as a liquid crystal polymer (LCP), syndiotactic polystyrene (SPS), polyphenylene sulfide (PPS), and epoxy. Terminals 11 and 12 are inserted into the case 10 by insert molding. These terminals 11 and 12 have bifurcated inner connection portions 11a and 12a, respectively. The inner connection portions 11a and 12a are exposed inside the two opposed sidewalls 10b and 10d, respectively, of the four sidewalls 10b to 10e. The terminals 11 and 12 also have outer connection portions 11b and 12b, respectively, exposed outside the case 10. The outer connection portions 11b and 12b are bent toward the bottom surface of the case 10 along the outer surfaces of the sidewalls 10b and 10d, respectively (see Fig. 6).

Supports 10f are formed inside the four corners of the case 10 to support the bottom surface of the diaphragm 1 at the corners thereof. These supports 10f are formed at a height one step lower than the exposed surfaces of the inner connection portions 11a and 12a of the terminals 11 and 12. When the diaphragm 1 is placed on the supports 10f, the top surface of the diaphragm 1 is positioned at substantially the same height as or slightly lower than the top

surfaces of the inner connection portions 11a and 12a of the terminals 11 and 12.

Urethane-receiving steps 10g are formed near the supports 10f inside the inner connection portions 11a and 12a of the terminals 11 and 12. These urethane-receiving steps 10g are positioned at a height lower than the supports 10f to define predetermined gaps D_1 between the urethane-receiving steps 10g and the bottom surface of the diaphragm 1. The gaps D_1 between the top surfaces of the urethane-receiving steps 10g and the bottom surface of the diaphragm 1 (the top surfaces of the supports 10f) have such a height that a first elastic adhesive 13, described later, can be prevented from flowing out by its surface tension. The gap D_1 is preferably about 0.1 to 0.2 mm if the first elastic adhesive 13 is applied with a viscosity of 6 to 10 Pa·s. In this embodiment, the gaps D_1 is 0.15 mm.

Grooves 10h to be filled with a second elastic adhesive 15, described later, are disposed on the periphery of the bottom wall 10a of the case 10. Flow-stopping walls 10i lower than the supports 10f are disposed on the inner side of the grooves 10h to prevent the second elastic adhesive 15 from flowing onto the bottom wall 10a. The gaps D_2 between the top surfaces of the flow-stopping walls 10i and the bottom surface of the diaphragm 1 (the top surfaces of

the supports 10f) have such a numeric value that the second elastic adhesive 15 can be prevented from flowing out by its surface tension. The gaps D_2 is preferably about 0.15 to 0.25 mm if the second elastic adhesive 15 is applied with a viscosity of 0.5 to 2.0 Pa·s. In this embodiment, the gaps D_2 is 0.20 mm.

In this embodiment, the bottom surfaces of the grooves 10h are positioned at a height upper than the top surface of the bottom wall 10a. The grooves 10h are so shallow that they can be fully filled with a relatively small amount of second elastic adhesive 15 and thus the adhesive 15 can be quickly spread over the grooves 10h. Specifically, the height D_3 from the bottom surfaces of the grooves 10h to the bottom surface of the diaphragm 1 (the top surfaces of the supports 10f) is adjusted to 0.30 mm. The grooves 10h and the walls 10i are disposed in the area of the periphery of the bottom wall 10a except the urethane-receiving steps 10g, although the grooves 10h and the walls 10i may also be disposed over the entire periphery of the bottom wall 10a so as to continuously extend via the inside of the urethane-receiving steps 10g.

The grooves 10h have wide end portions (at the four corners) in contact with the supports 10f and the urethane-receiving steps 10g. These wide portions can hold an excess of the adhesive 15 to prevent the overflow thereof onto the top of the diaphragm 1.

Two overamplitude-preventing receivers 10p are disposed closer to the center of the piezoelectric diaphragm 1 than the supports 10f to limit the amplitude of vibration of the diaphragm 1 to a predetermined range. These overamplitude-preventing receivers 10p are positioned at a corner of the bottom wall 10a of the case 10 near the lead electrode 9b and the diagonal corner thereof so as to protrude integrally from the bottom wall 10a. In this embodiment, the receivers 10p are adjacent to the inner periphery side of the walls 10i. The receivers 10p are preferably positioned below areas where a conductive adhesive 14 is applied. The receivers 10p need not cover the entire areas where the conductive adhesive 14 is applied and may be disposed immediately below the ends of the areas facing the center of the diaphragm 1. The distance D_4 between the bottom surface of the diaphragm 1 and the top surfaces of the overamplitude-preventing receivers 10p is determined so that the diaphragm 1 does not come into contact with the receivers 10p in normal operation.

The distance D_4 is preferably adjusted to 0.01 to 0.2 mm if the piezoelectric diaphragm 1 used includes a metal plate 2 having a size of 7.6 mm by 7.6 mm by 0.03 mm and a piezoelectric element 4 having a size of 6.8 mm by 6.0 mm by 0.04 mm and is supported at the four corners thereof. In this embodiment, the distance D_4 is

adjusted to 0.05 mm, and the receivers 10p have an area of 0.36 mm^2. The gaps between the diaphragm 1 and the overamplitude-preventing receivers 10p are filled with the second elastic adhesive 15 (see Fig. 11).

If a drop impact, for example, is applied to the piezoelectric sounder, an acceleration G bends the diaphragm 1 downward with the supports 10f as a fulcrum. The overamplitude-preventing receivers 10p then limit an excessive amplitude of vibration of the diaphragm 1 to avoid an excessive tension acting on the conductive adhesive 14, described later, thus preventing the cracking of the conductive adhesive 14. Even if the acceleration G is so large that the diaphragm 1 comes into contact with the receivers 10p, the second elastic adhesive 15 can softly receive the diaphragm 1 to avoid an excessive impact on the diaphragm 1, thus protecting the diaphragm 1.

Fig. 12 is a graph showing the relationship between the distance D_4 between the receivers 10p and the diaphragm 1 and sound pressures at 4 kHz. Fig. 12 shows that sound pressures at 4 kHz of 75 dB or more can be achieved with variations of only about 0.2 dB if the distance D_4 is adjusted to 0.01 mm or more. The piezoelectric sounder thus has excellent sound pressure characteristics.

Fig. 13 is a graph showing the relationship between the distance D_4 between the receivers 10p and the diaphragm 1 and defect rates

in a drop impact test.

The drop impact test was performed by dropping cellular phones incorporating piezoelectric sounders onto a concrete surface from a height of 150 cm and determining whether or not the conductive adhesive 14 was cracked after ten cycles of dropping in six directions/cycle. The piezoelectric sounders were determined to be defective if the conductive adhesive 14 was cracked.

Fig. 13 clearly shows that the defect rate remained 0% if the distance D_4 was 0.2 mm or less and rose if the distance D_4 exceeded 0.2 mm. These results demonstrate that the conductive adhesive 14 was cracked and exhibited decreased connection reliability if the distance D_4 exceeded 0.2 mm.

Accordingly, the distance D_4 between the bottom surface of the diaphragm 1 and the top surfaces of the receivers 10p is preferably adjusted to 0.01 to 0.2 mm.

Two tapered protrusions 10j are disposed on the inner surface of each of the sidewalls 10b to 10e to guide the four corners of the piezoelectric diaphragm 1.

Recesses 10k are formed at the inner top edges of the sidewalls 10b to 10e of the case 10 to prevent the second elastic adhesive 15 from climbing up.

A first sound-emitting hole 10l is formed in the bottom wall

10a near the sidewall 10e.

Substantially L-shaped positioning protrusions 10m are formed at the corners of the top surfaces of the sidewalls 10b to 10e of the case 10 to fit to and hold the corners of the cover 20. The protrusions 10m have inner tapered surfaces 10n for guiding the cover 20.

The piezoelectric diaphragm 1 is incorporated in the case 10 with the metal plate 2 facing the bottom wall 10a. The supports 10f support the corners of the metal plate 2. The tapered protrusions 10j, which are disposed on the inner surfaces of the sidewalls 10b to 10e, guide the edges of the diaphragm 1 so that the corners thereof can be accurately placed on the supports 10f. In particular, the tapered protrusions 10j allow a clearance between the diaphragm 1 and the case 10 to be narrowed with accuracy exceeding the accuracy with which the diaphragm 1 is inserted. This results in a smaller product size. In addition, the vibration of the diaphragm 1 is not obstructed because the contact areas between the protrusions 10j and the edges of the diaphragm 1 are small.

After the diaphragm 1 is incorporated in the case 10, the first elastic adhesive 13 is applied to four places near the corners of the diaphragm 1 to secure the diaphragm 1 (particularly, the metal plate 2) to the inner connection portions 11a and 12a of the terminals

11 and 12, as shown in Fig. 7. That is, the first elastic adhesive 13 is applied to two diagonal positions, namely, between the lead electrode 9b and one of the inner connection portions 11a of the terminal 11 and between the top outer electrode 6 and one of the inner connection portions 12a of the terminal 12. The first elastic adhesive 13 is also applied to the other two diagonal positions. The first elastic adhesive 13 is applied in a line in this embodiment, although the shape thereof is not limited to the linear shape. The first elastic adhesive 13 preferably has a Young's modulus of 500 x 10^6 Pa or less after being cured. A urethane adhesive having a Young's modulus of 3.7 x 10^6 Pa is used in this embodiment. The applied first elastic adhesive 13 is cured by heating.

The first elastic adhesive 13, when applied, may flow onto the bottom wall 10a through the gaps between the piezoelectric diaphragm 1 and the terminals 11 and 12 because of its low viscosity. As shown in Fig. 9, the urethane-receiving steps 10g are defined below the piezoelectric diaphragm 1 in the areas where the first elastic adhesive 13 is applied. The gaps D_1 between the urethane-receiving steps 10g and the piezoelectric diaphragm 1 are so narrow that the first elastic adhesive 13 is prevented from flowing onto the bottom wall 10a by its surface tension. In addition, the gaps D_1 are quickly filled with the first elastic adhesive 13, and

an excess thereof forms bumps between the piezoelectric diaphragm 1 and the terminals 11 and 12. The piezoelectric diaphragm 1 is not excessively restrained because the elastic adhesive 13 forms a layer filling the gaps D_1 between the urethane-receiving steps 10g and the piezoelectric diaphragm 1.

After the first elastic adhesive 13 is cured, the conductive adhesive 14 is applied across the first elastic adhesive 13. The conductive adhesive 14 used is not particularly limited; a urethane-based conductive paste having a Young's modulus after curing of 0.3×10^9 Pa is used in this embodiment. The applied conductive adhesive 14 is cured by heating to connect the lead electrode 9b to the inner connection portion 11a of the terminal 11 and to connect the top outer electrode 6 to the inner connection portion 12a of the terminal 12. The conductive adhesive 14 is also applied to the metal plate 2, but does not come into direct contact therewith because the insulating layer 3a is disposed on the metal plate 2 in advance and the first elastic adhesive 13 covers the edges of the metal plate 2. The shape of the applied conductive adhesive 14 is not particularly limited, and may be any shape that allows the conductive adhesive 14 to connect the lead electrode 9b to the inner connection portion 11a and to connect the outer electrode 6 to the inner connection portion 12a via the top surfaces of the first elastic adhesive 13.

The conductive adhesive 14 is applied in the shape of an arch across the top surfaces of the bumps of the first elastic adhesive 13, thus extending on the shortest route (see Fig. 9). The first elastic adhesive 13 relieves a stress due to the curing and contraction of the conductive adhesive 14 to reduce the effect thereof on the piezoelectric diaphragm 1.

After the conductive adhesive 14 is applied and cured, the second elastic adhesive 15 is applied into the gaps between the entire periphery of the diaphragm 1 and the inner portion of the case 10 to prevent air from leaking from the spaces above and below the diaphragm 1 to each other. The second elastic adhesive 15 applied around the diaphragm 1 is cured by heating. The second elastic adhesive 15 used is preferably a thermosetting adhesive having a Young's modulus of about 30×10^6 Pa or less after being cured and having a low viscosity, namely, about 0.5 to 2 Pa·s, before being cured. A silicone adhesive having a Young's modulus of 3.0×10^5 Pa is used in this embodiment.

The second elastic adhesive 15, when applied, may flow onto the bottom wall 10a through the gaps between the piezoelectric diaphragm 1 and the case 10 because of its low viscosity. As shown in Fig. 10, the grooves 10h, which are to be filled with the second elastic adhesive 15, are defined on the inner portion of the case

10 opposite the periphery of the diaphragm 1, and the flow-stopping walls 10i are disposed on the inner side of the grooves 10h. The second elastic adhesive 15 flows into and spreads over the grooves 10h. The gaps D_2 are defined between the diaphragm 1 and the flow-stopping walls 10i so that the second elastic adhesive 15 is held in the gaps D_2 by its surface tension. The gaps D_2 thus prevent the second elastic adhesive 15 from flowing onto the bottom wall 10a. In addition, the elastic adhesive 15 forms a layer filling the gaps D_2 between the walls 10i and the piezoelectric diaphragm 1 to prevent the vibration of the piezoelectric diaphragm 1 from being restrained.

The gaps D_2 are slightly larger than the gaps D_1 (D_1 = 0.05 mm and D_2 = 0.15 mm) in this embodiment. The first elastic adhesive 13 is applied to parts of the piezoelectric diaphragm 1, that is, to only the opposite portions of the piezoelectric diaphragm 1 and the terminals 11 and 12, while the second elastic adhesive 15 is applied substantially over the entire periphery of the piezoelectric diaphragm 1. To minimize the binding force of the second elastic adhesive 15 on the piezoelectric diaphragm 1, the gaps D_2 are maximized within such a range that the second elastic adhesive 15 does not leak. The binding force of the first elastic adhesive 13, which is applied to the limited areas, has little effect even if the gaps

D_1 are narrowed. The gaps D_1 are therefore defined so as to minimize the amount of adhesive 13 used to form the bumps between the piezoelectric diaphragm 1 and the terminals 11 and 12.

Part of the applied second elastic adhesive 15 can clime up and adhere to the top surfaces of the sidewalls. If the second elastic adhesive 15 used is a sealant having mold release properties, such as a silicone adhesive, the adhesive 15 can decrease the bonding strength with which the cover 20 is bonded to the top surfaces of the sidewalls 10b to 10e. The recesses 10k is therefore formed at the inner top edges of the sidewalls 10b to 10e to prevent the second elastic adhesive 15 from climbing up and adhering to the top surfaces of the sidewalls.

After the diaphragm 1 is attached to the case 10 as described above, the cover 20 is bonded to the top surfaces of the sidewalls 10b to 10e of the case 10 with an adhesive 21. The adhesive 21 used may be a known adhesive such as an epoxy adhesive. A silicone adhesive may be used as the adhesive 21 if the second elastic adhesive 15 used is a silicone adhesive because the adhesive can produce siloxane gas and deposit a coating thereof on the top surfaces of the sidewalls 10b to 10e of the case 10. The cover 20 is formed of a material similar to the material for the case 10 and has a flat shape. The cover 20 is accurately positioned by allowing the edges thereof to

engage with the tapered surfaces 10n of the positioning protrusions 10m on the top surfaces of the sidewalls 10b to 10e of the case 10. The cover 20 is bonded to the case 10 to define an acoustic space between the cover 20 and the diaphragm 1. The cover 20A has a second sound-emitting hole 22.

Thus, a surface-mount piezoelectric electroacoustic transducer is finished.

In this embodiment, a predetermined periodic voltage (alternating signals or rectangular signals) is applied across the terminals 11 and 12 to expand and contract the piezoelectric element 4 in a plane while the metal plate 2 does not expand or contract. The diaphragm 1 can thus be bent and vibrated on the whole. The diaphragm 1 can then emit a predetermined sound wave through the sound-emitting hole 22 because the second elastic adhesive 15 seals the spaces above and below the diaphragm 1.

In particular, the diaphragm 1 can produce a higher sound pressure because the supports 10f support the diaphragm 1 at the corners thereof with a small supporting area. In addition, the electroacoustic transducer has stable frequency characteristics because the first elastic adhesive 13 is disposed below the conductive adhesive 14 to inhibit a strain imposed on the diaphragm 1 by a stress due to the curing and contraction of the conductive adhesive 14.

Furthermore, the cured conductive adhesive 14 does not obstruct the vibration of the diaphragm 1 or is not cracked by the vibration of the diaphragm 1.

The present invention is not limited to the embodiment described above and may be modified within the scope of the invention.

The area where the second elastic adhesive 15 is applied is not limited to the entire periphery of the diaphragm 1 as in the embodiment described above; it may be applied to any area where it can seal the gaps between the diaphragm 1 and the case 10.

Although the piezoelectric diaphragm 1 has a structure composed of the metal plate and the multilayer piezoelectric element 4 bonded thereto in this embodiment, the piezoelectric element used may also have a monolayer structure.

The piezoelectric diaphragm of the present invention is not limited to a unimorph piezoelectric diaphragm including a metal plate and a piezoelectric element bonded thereto, and a bimorph piezoelectric diaphragm including only a multilayer piezoelectric ceramic element as disclosed in Japanese Unexamined Patent Application Publication No. 2001-95094 may be used.

The casing of the present invention is not limited to the casing including the case 10, which has a box shape in cross section, and the cover 20, which is bonded to the top opening of the case 10,

in the embodiment described above. For example, the casing used may include a cap-like case with a bottom opening and a substrate bonded to the bottom of the case.

The receivers 10p are disposed at the two diagonal positions in the embodiment described above, although the number of the receivers 10p may be increased according to the positions where the conductive adhesive 14 is applied.

Brief Description of the Drawings

Fig. 1 is an exploded perspective view of a piezoelectric electroacoustic transducer according to a first embodiment of the present invention.

Fig. 2 is an exploded perspective view of a piezoelectric diaphragm used in the piezoelectric electroacoustic transducer in Fig. 1.

Fig. 3 is a sectional view of the piezoelectric diaphragm.

Fig. 4 is a plan view of a case used for the piezoelectric electroacoustic transducer in Fig. 1.

Fig. 5 is a sectional view taken along line V-V in Fig. 4.

Fig. 6 is a sectional view taken along line VI-VI in Fig. 4.

Fig. 7 is a plan view of the case in Fig. 4, which holds the diaphragm (before the application of a second elastic adhesive).

Fig. 8 is an enlarged perspective view of a corner of the case in Fig. 4.

Fig. 9 is an enlarged sectional view taken along line IX-IX in Fig. 7.

Fig. 10 is an enlarged sectional view taken along line X-X in Fig. 7.

Fig. 11 illustrates a sectional view taken along line XI-XI in Fig. 7 and a sectional view showing the action of a drop impact.

Fig. 12 is a graph showing the relationship between the distance D_4 between overamplitude-preventing receivers and the piezoelectric diaphragm and sound pressures at 4 kHz.

Fig. 13 is a graph showing the relationship between the distance D_4 between the overamplitude-preventing receivers and the piezoelectric diaphragm and defect rates in a drop impact test.

Fig. 14 illustrates sectional views of a connection portion between a piezoelectric diaphragm and a terminal in a known structure.

Reference Numerals

1: piezoelectric diaphragm

2: metal plate

4: piezoelectric element

6: outer electrode

9b: lead electrode

10: case

10a: bottom wall

10f: support

10p: overamplitude-preventing receiver

11 and 12: terminal

13: first elastic adhesive

14: conductive adhesive

15: second elastic adhesive